NAVAL POSTGRADUATE SCHOOL
MONTEREY, CALIFORNIA

THESIS

DESIGN OF AN ARTICULATED MANIPULATOR FOR ENHANCED DEXTERITY IN MINIMALLY INVASIVE SURGERY

by

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A current limitation in minimally invasive surgical (MIS) procedures is the lack of an articulated mechanism which will provide dexterity inside the torso while supporting a surgical tool. The tool could be a pair of scissors or an optical device such as a camera, or both. To overcome this limitation we have designed an Articulated Manipulator for Minimally Invasive Surgery (AMMIS). The AMMIS is expected to provide surgeons with improved dexterity during MIS procedures and be ideally suited for tele-surgery. This design may also be used in non-medical applications such as aviation maintenance, and engine inspection.

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DESIGN OF AN ARTICULATED MANIPULATOR FOR ENHANCED DEXTERITY IN MINIMALLY INVASIVE SURGERY

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ABSTRACT

A current limitation in minimally invasive surgical (MIS) procedures is the lack of an articulated mechanism which will provide dexterity inside the torso while supporting a surgical tool. The tool could be a pair of scissors or an optical device such as a camera, or both. To overcome this limitation we have designed an Articulated Manipulator for Minimally Invasive Surgery (AMMIS). The AMMIS is expected to provide surgeons with improved dexterity during MIS procedures and be ideally suited for tele-surgery. This design may also be used in non-medical applications such as aviation maintenance, and engine inspection.

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I. INTRODUCTION

A. MOTIVATION

Since the late 1980's, Minimally Invasive Surgery (MIS) has gained widespread acceptance because of the significant advantages realized by the patient in the form of reduced trauma, recovery time and total procedural costs. It is widely accepted as a safe and cost-effective procedure and millions have been performed to date. A current limitation in MIS procedures, laparoscopic surgery for example, is the lack of an articulated mechanism which will provide dexterity inside the torso while supporting a surgical tool such as a pair of scissors or an optical device such as a camera, or both. In the case of laparoscopic surgery, the instrument commonly used is a single-purpose rigid link supporting either a surgical tool or a camera. The lack of a multi-purpose articulated instrument has hindered the continued growth in the number of MIS procedures.

To provide improved dexterity during Minimally Invasive Surgery (MIS) an Articulated Manipulator for Minimally Invasive Surgery (AMMIS) has been developed at the US Naval Postgraduate School. The AMMIS achieves dexterity using the minimum number of actuators: the use of fewer actuators enable the miniaturization of the articulated structure and provides space for the accommodation of peripheral devices that add functionalities to the manipulator.

B. BACKGROUND

The existing state-of-the-art in dexterous instruments, produced by Ethicon Endo-Surgery, involves a rigid link with a short tip that can bend up to 90 degrees uni-directionally [Ref. 1]. This system provides better maneuvering capability than a completely rigid tool but is far from providing the desired level of dexterity that a surgeon would like to have. A surgeon may need to approach an internal organ within the torso with an arbitrary orientation, such as in the case of inserting a catheter inside the common bile duct for exploration and or removal of stones. Such procedures are quite difficult to perform in the absence of dexterous instrumentation. A dexterous mechanism for MIS would be required to have the following features:

(a) The mechanism should be small in size so that it can pass through a standard trocar sleeve, 10 millimeter or less, in diameter,

(b) The manipulator should provide articulation by bending up to 180 degrees, bi-directionally,

(c) It should be able to apply sufficient forces as required during standard MIS procedures, and

(d) It should be able to support a surgical tool, or an optical device, or both, at its distal end.

Currently, there are a number of articulated mechanisms for MIS in their research stages. These are commonly driven by shape memory alloy (SMA) actuators [Ref. 2-4]

or tendons [Ref. 5,6] or electro-pneumatic systems [Ref. 7]. An SMA wire actuated mechanism can apply a large force but cannot make sharp bends. Manipulators employing SMA springs can make sharp bends but cannot apply large forces. Also, SMA actuators have a slow response time in general. Articulated mechanisms using tendons cannot be easily miniaturized and are inherently difficult to control. Electro-pneumatic systems are highly nonlinear and are also difficult to control. These limitations led us to develop a mechanism that would achieve the design criteria and meet the desired features previously mentioned. A schematic of this mechanism, the AMMIS, in various configurations during a MIS procedure is portrayed in Figure 1.

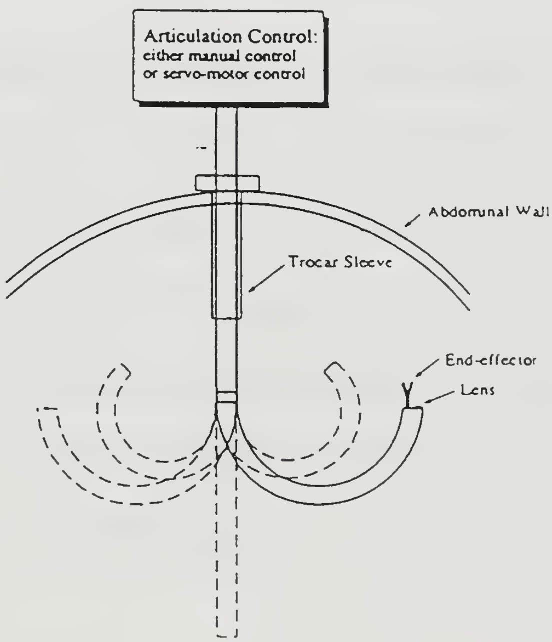

Figure 1. A Conceptual Diagram Showing the AMMIS in Various Configurations During a Minimally Invasive Surgical Procedure

II. DESIGN OF THE ARTICULATED MECHANISM

A. LINKAGE DESIGN AND OPERATION

To overcome the limitations of currently available surgical instruments and to improve dexterity during Minimally Invasive Surgery (MIS) an Articulated Manipulator for Minimally Invasive Surgery (AMMIS) has been developed at the US Naval Postgraduate School. The central idea behind the AMMIS design is to concatenate a series of linkages in which every link is both a driven-link and a driving-link. Using this idea, the power from a single actuator located at the base link can be transmitted to the end of the chain of linkages while providing articulation to each and every one of the linkages in between.

The conceptual manipulator discussed above can be realized by the mechanism illustrated in Figure 2. This Figure provides a three-dimensional view of a four-link articulated manipulator chain with a driving gear located on Link-0, which serves as the base of the manipulator. Gear-1 is the driving gear and can be connected to a servo-motor or can be driven manually. All gears in this particular design have the same pitch number and pitch diameter - this only simplifies our discussion and should not be interpreted as a limitation of the AMMIS design.

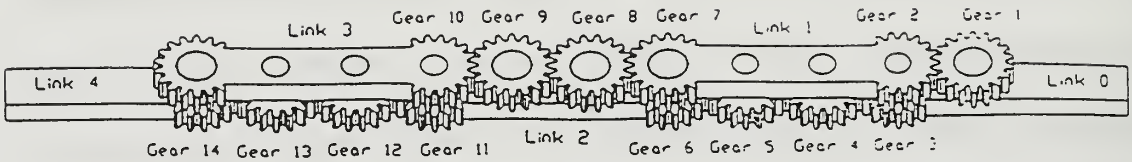

Figure 2. The Articulated Manipulator for Minimally Invasive Surgery (AMMIS)

To understand the principle of operation of the four-link AMMIS in Figure 2, we first notice that Gear-2 is a part of Link-1. As Gear-1, the driving gear, rotates β degrees clockwise (cw), Gear-2 and Link-1 will simultaneously rotate β degrees in the counter-clockwise (ccw) direction about the common axes of Gear-2 and Gear-3. Gear-4 is mounted on Link-1 and is meshed with Gear-3 which cannot rotate about its own axis. Therefore, as Link-1 rotates ccw, Gear-4 behaves as a planetary gear to Gear-3 and rotates ccw about its own axis. Gear-5 is meshed together with Gear-4 and Gear-6. Thus Gear-6 rotates β degrees ccw as Gear-4 rotates β degrees ccw. Gear-6 is rigidly connected to Link-2; this implies that Link-2 will rotate β degrees in the ccw direction with respect to Link-1 about the common axes of Gear-6 and Gear-7. As Gear-6 rotates β

degrees ccw, Gear-8 behaves as a planetary gear to Gear-7, which cannot rotate, relative to Link-1 bout its own axis. Therefore Gear-8 transmits the power from Link-2 to Link-3.

Using the same reasoning as above, we can show that Link-3 will rotate β degrees ccw with respect to Link-2 about the common axes of Gear-10 and Gear-11, and Link-4 will also rotate β degrees ccw with respect to Link-3 about the axis of Gear-14. Therefore, the AMMIS represents a mechanism where each link rotates β degrees ccw with respect to the previous link as the driving gear rotates β degrees cw. In effect, we achieve a total of 4β degrees ccw rotation at the end of Link-4 of this four link AMMIS with respect to the base link, Link-0, as shown in Figure 3.

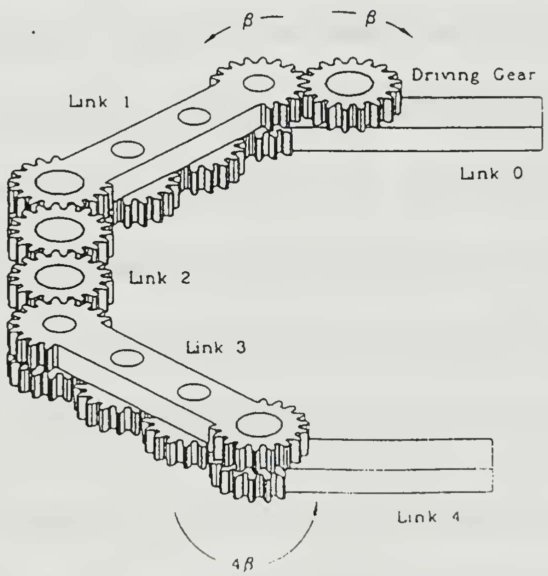

Figure 3. An Articulated Configuration of the AMMIS

B. CONFIGURATIONS AND DESIGN ALTERNATIVES

If one or more linkages are added to the 4-link AMMIS, increased articulation can be achieved. Also, by rotating the driving gear cw and ccw, bi-directional articulation can be achieved.

In the AMMIS design presented here, the magnitude of rotation between adjacent linkages are the same and are equal to the magnitude of rotation of the driving gear. This is due to the fact that the gear ratios between adjacent linkages were chosen to be unity. The magnitudes of rotation of adjacent linkages can be made to differ by choosing gears of varying pitch diameter. This can be used for achieving different shapes of articulation.

In the AMMIS design presented here, each linkage has two gears for the transmission of power from the previous link to the next. An addition of an even number of gears to any particular linkage enables us to change the length of that link and hence the shape of articulation of the manipulator, while maintaining the uniformity in the direction of rotation of every link. If an odd number of gears are added to a link, the direction of rotation of the next link is reversed with respect to that particular link. An AMMIS can therefore be designed to achieve various forms of articulation using different number of gears per link while using a single driving mechanism.

Though the embodiment of the AMMIS, discussed above, can provide a substantial degree of articulation, it is essentially a single degree-of-freedom mechanism since the different links of the AMMIS cannot be moved independently relative to each other. An AMMIS can be designed with multiple driving mechanisms (actuators)

controlling two connected, yet independently controllable portions of the AMMIS, thereby to achieve multiple degrees-of-freedom for more complex articulation. For example, a plurality of intermeshing gears could be provided on a first portion, extending from the proximal end of the first portion to its distal end, thereby to manipulate a second portion connected to the distal end of the first portion. In such an embodiment, the first and second portions together constitute a complex two-actuator AMMIS with two independent actuators.

III. ANALYSIS OF THE MECHANISM

A. KINEMATIC ANALYSIS

The articulated mechanism was designed to be a single degree of freedom system. This will simplify the control of its articulated motion and makes it easier to miniaturize the design. A study of the kinematics of the mechanism was done to study the trajectory followed by the tip of the articulated mechanism. Figure 4 shows the path followed by the tip of the articulated mechanism, if the driver gear is located at (0,0) and the link initially is in a straight configuration to the right. This enabled us to see how much articulation could be expected from the design. The driver gear is rotated until an angle of 72 degrees which is the point in which the end link would touch the base link. Superimposed on Figure 4 are intermediate configurations of the links.

The reachable workspace of the AMMIS is seen in Figure 5. The Figure shows the tip travel covered bi-directionally when the surgical instrument is inserted straight into the stomach. By using point A as a fulcrum and positioning the surgical instrument at oblique angles on either side of the straight position the arch can cover a complete area. By moving the shaft in and out the area covered can be changed, and rotating the shaft allows for additional volume coverage. The AMMIS can therefore reach almost any point within the abdomen.

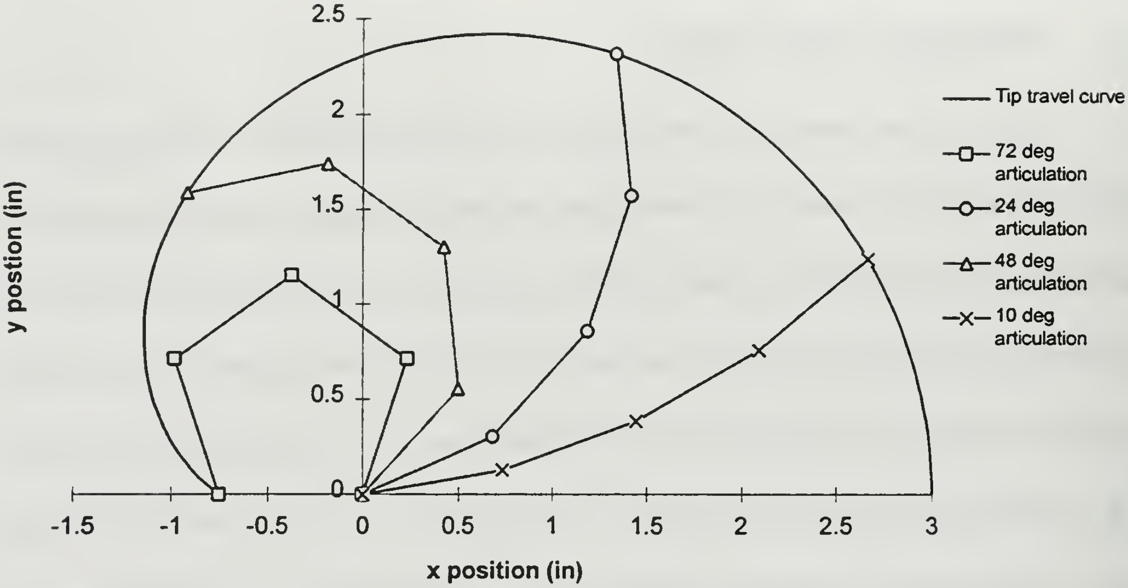

Figure 4. Plot of Tip of the Articulated Mechanism

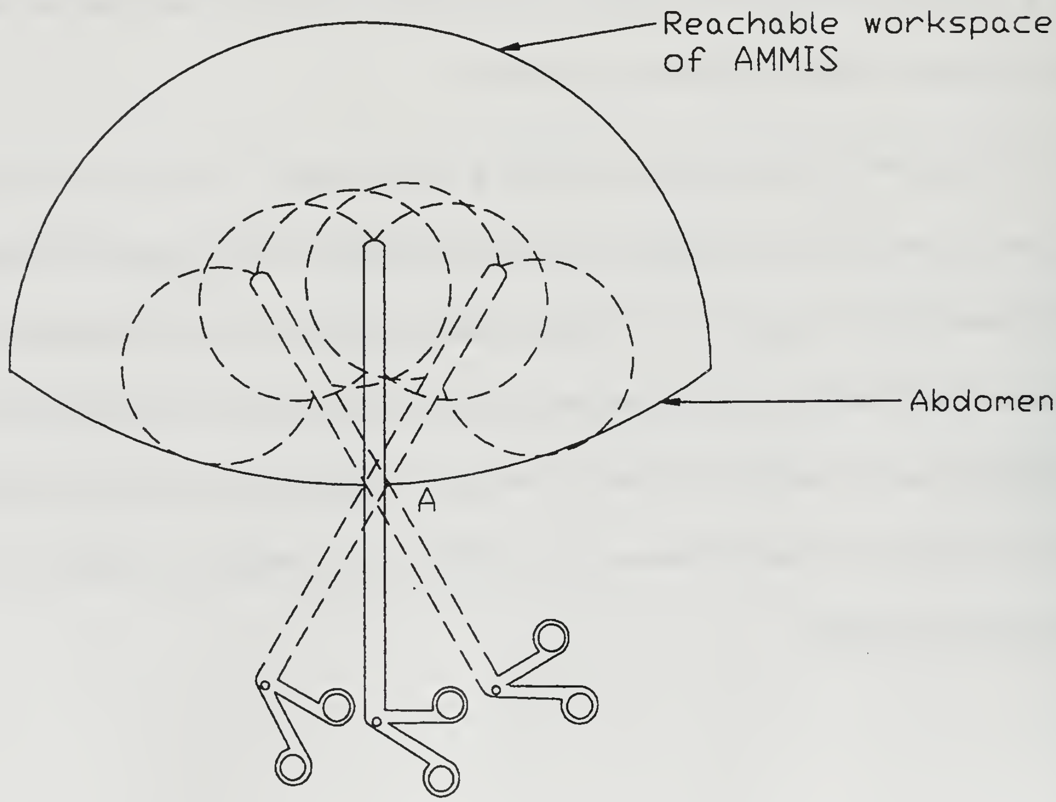

Figure 5. A Schematic of the Coverage the AMMIS has within the Abdomen during MIS procedures

B. STRESS ANALYSIS USING FEM

1. Modeling Technique

A finite element model of the four link articulated mechanism was created using IDEAS master series software. A first attempt was made at modeling the exact design and the precise involute profile. This was not a practical way to model the problem. The size of the model was enormous and the software was unable to mesh the geometry. A new approach to modeling was undertaken. Instead of modeling the precise detail of the gear teeth, an eight node parabolic thin shell element was used to model the bending of the gear teeth. The thickness of the shell element was chosen to be the thickness of the gear tooth at the pitch circle. The shell elements were embedded in discs with a diameter of the dedendum circle as shown in Figure 6. Ideas has a partitioning function that allows the user to cut the solid model, in order to control where the nodes are placed. The discs were partitioned to ensure a line of nodes through the center of the discs. The rigid links were partitioned to ensure a line of nodes goes through the center of the axis of rotation for the gears that ride above the link. By partitioning the model in this manner the gear and the rigid link meet at the nodes that are coincident and are along the axis of rotation. This allows for a coupled degree of freedom at the coincident nodes and enables us to simulate a relative rotation between the gear and the link.

Six models were analyzed using the properties of general isotropic steel. The models were varied by a ten degree rotation of the driver gear up to 50 degrees. Each model was then tested by applying a one pound force at different angles to the face of the end link. The force application angle was varied from zero degrees to 180 degrees in steps of 15 degrees. This created 13 different loading cases for each model. Figure 7 shows the 30 degree articulated model with a load application angle of 45 degrees corresponding to case four.

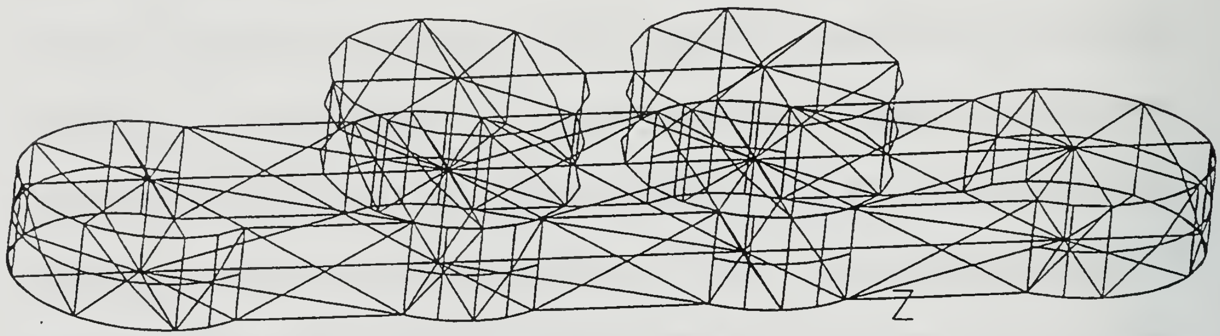

Figure 6. A Finite Element Model of the four-link AMMIS

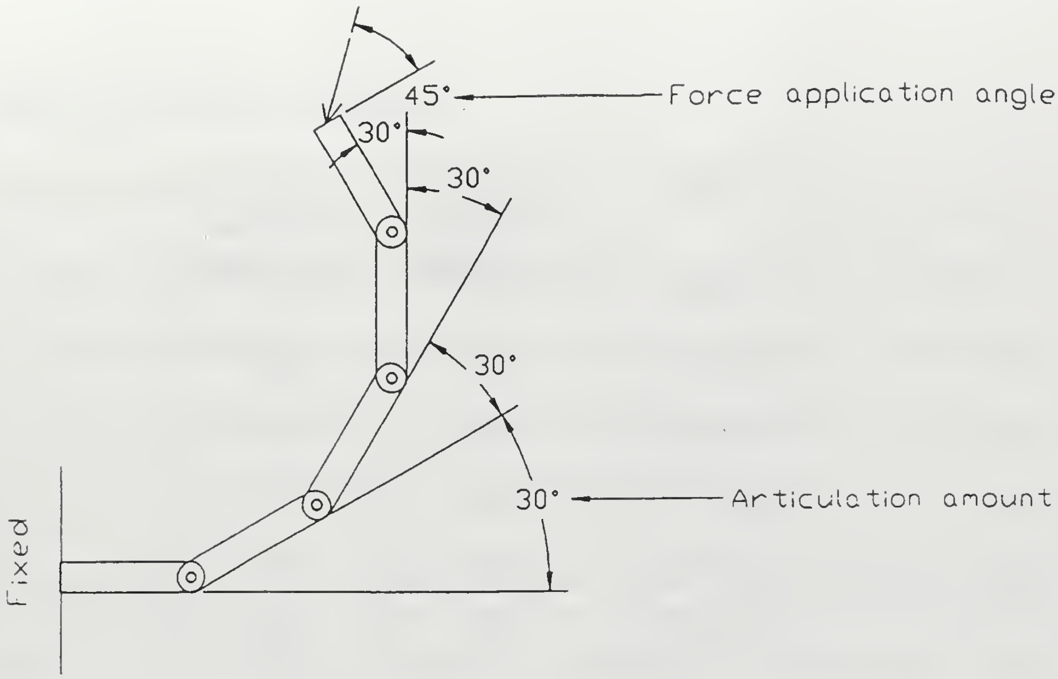

Figure 7. A schematic of the Application of Force to the Finite Element Model

2. Results

The 13 cases were run for each of the six different models. The results are summarized in table 1 and Figure 8. The maximum Von Mises stress occurred in the straight model with a force perpendicular to the face [Ref. 8]. This is due to the maximum bending moment in this configuration. For the other models the trends show the maximum stress occurred when the force was around 150 degrees.

Model	Maximum Von Mises Stress (kpsi)	Force Application Angle (deg)
Straight	35.5	0
10 deg model	19.0	165
20 deg model	33.6	150
30 deg model	20.6	150
40 deg model	24.2	150
50 deg model	20.2	165

Table 1. Results of Finite Element Analysis

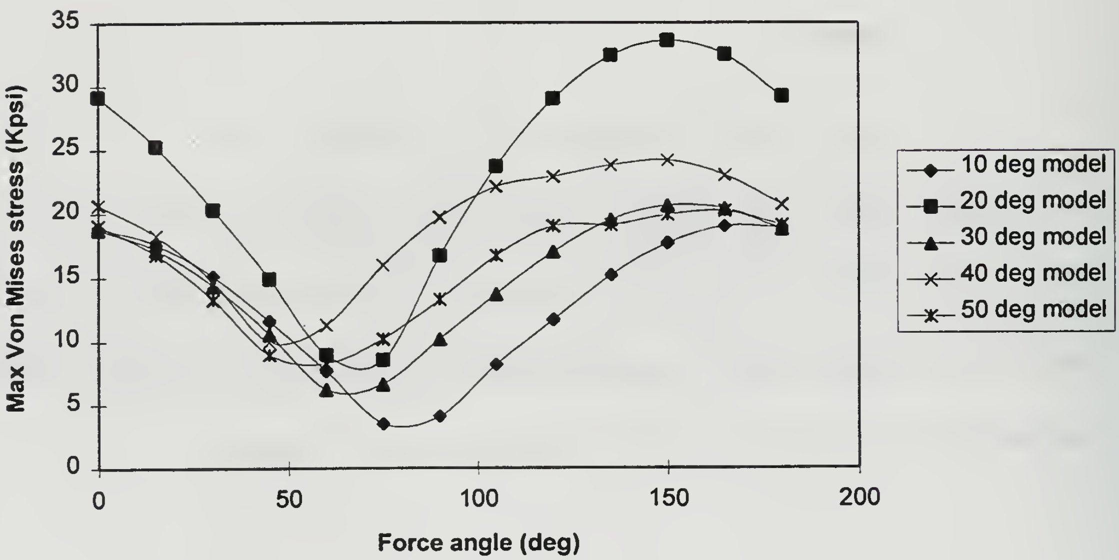

Figure 8. Plot of Maximum Von Mises Stresses Versus Force Angle

C. EVALUATION OF DESIGN

The mechanism design meets the requirements of articulation and gives the added dexterity needed to perform minimally invasive surgical procedures. The mechanism is capable of withstanding small forces encountered during these procedures. The prototype was built with 4304 stainless steel. This has a yield strength of 40 kpsi and ultimate strength of 82.4 kpsi [Ref. 8]. The worst case gives a factor of safety of 1.12. A one pound force is typically expected for MIS procedures. With varying materials a higher factor of safety can be achieved. The size of the mechanism is small enough to pass through a standard trocar of 10 mm in diameter. The mechanism is capable of carrying a surgical tool or an optical device or both at the distal end. This design meets the design criteria established for it in section 1B.

IV. DESIGN OF AN ARTICULATED SURGICAL INSTRUMENT

A. INTEGRATION OF AMMIS INTO A SURGICAL INSTRUMENT

The AMMIS is capable of fine and dexterous manipulation. It can be designed to adopt a serpentine curve of tight radius and make bends of 180 degrees or more bi-directionally. However, by itself, the AMMIS cannot be used in surgical procedures. The capability of AMMIS can be utilized by designing a surgical tool to accompany AMMIS. One possible design could be to attach the AMMIS to the distal end of a rigid surgical tool and connect endeffectors to the AMMIS such that the combination can behave as a dexterous surgical instrument. As we consider this design we conceive of three problems that need to be addressed immediately: (1) Power transmission from proximal end of the surgical instrument to the proximal end of the AMMIS for articulation of the AMMIS (2) Control and actuation of the endeffector (3) Control and actuation of the roll of the endeffector.

The idea of the AMMIS is that the power from a single actuator can be transmitted to the end of the chain of linkages while providing articulation to each and every one of the linkages in between. In the proposed design the actuator would be on the surgical tool and therefore would require a device to transfer the power from the actuator on the tool to the driver gear on the AMMIS. To solve this problem two solutions have been investigated: 1.) a pulley cable system and 2.) a twin rack and pinion system. The first design is illustrated in Figure 9. The Pulley cable system is comprised of two pulleys, one located on the surgical tool and one located on the base

link of the AMMIS. By turning the pulley on the tool either manually with a turning knob, or using servo-motors, the cable moves and rotates the pulley on the AMMIS. This in turn drives the driver gear and articulates the AMMIS. The other alternative would be to have a twin rack and pinion design in which a gear pinion located on the surgical tool and one on the base link of the AMMIS would be connected by two racks one on each side. By turning the pinion gear on the tool either manually with a turning knob, or using a servo-motor, the pinion gear on the base link of the AMMIS can be made to rotate to achieve articulation of the AMMIS. The advantage of the twin rack and pinion over a single rack and pinion is the increased stiffness in the rack system which decreases the chance of the rack buckling under load.

The control and actuation of the endeffector is solved by the use of a push pull cable. This cable will be flexible enough to bend with the articulation of the AMMIS and stiff enough to actuate the endeffector. The endeffector will be actuated by pushing or pulling the cable as seen in Figure 9 at location 3.

The control of the roll of the endeffector is achieved by using a torsionaly rigid but flexible in bending, superelastic alloy (SEA) tube. The tube is hollow and will house the push pull cable as discussed above. The tube can be rotated as seen in item 2 in Figure 9, in order to roll the endeffector.

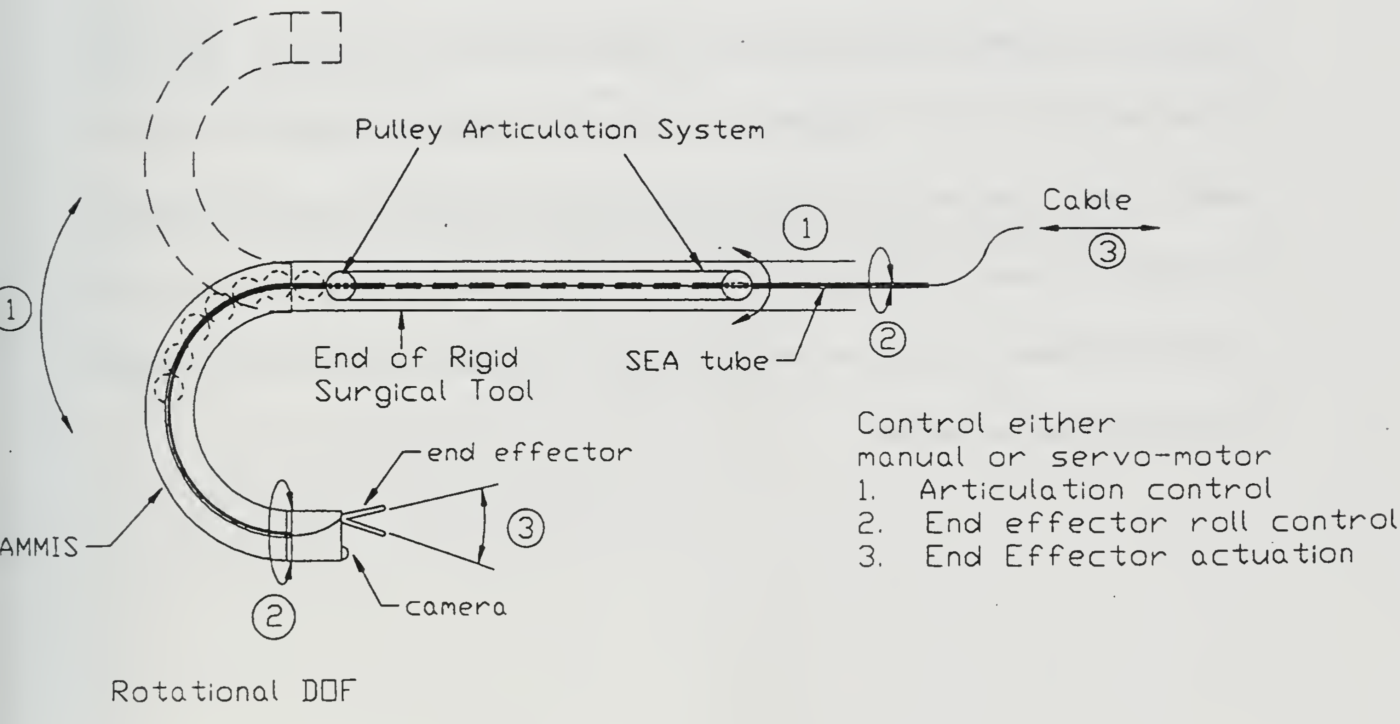

Figure 9. A Schematic of the AMMIS Attaced to the end of a Rigid Surgical Tool

B. DESCRIPTION OF COMPONENTS OF A DEXTEROUS SURGICAL INSTRUMENT

The AMMIS combined with a surgical tool and an endeffector can function as a dexterous surgical instrument for minimally invasive surgical procedures. Currently there are no commercially available surgical tools to which the AMMIS can be conveniently attached. Therefore we must design a surgical tool that can be integrated with the AMMIS to function together as one dexterous surgical instrument. Each component of this system must be designed so that it can be easily manufactured with minimal expense in order to produce a dexterous surgical instrument in mass quantity. One such design of a surgical instrument to incorporate the AMMIS has been designed at the Naval Postgraduate School. The components of this dexterous surgical instrument design are listed in Table 2 along with the quantity needed to build a dexterous surgical instrument. The detailed engineering drawing for each of the component parts follow. The next section will discuss in detail the assembly of the component parts to make the whole dexterous surgical instrument.

Part name	Quantity
1st Gear link	1
Standard connecting gear link	3
End gear link	1
2 mm standard gear	10
3 mm gear	1
3 mm gear with slot	1
Threaded rod	1
Top knob	1
Handle	1
Trigger	1
End plug	1
End knob	1
pin with chamfer	19
Stainless steel tube with slots	1
3 mm wheel	1
Sliding plug	1
front plug	1
End effector adapter	1

Table 2. List of Component Parts for a Dexterous Surgical Instrument

Figure 10. Assembly of all Component Parts to Make a Dexterous Surgical Instrument

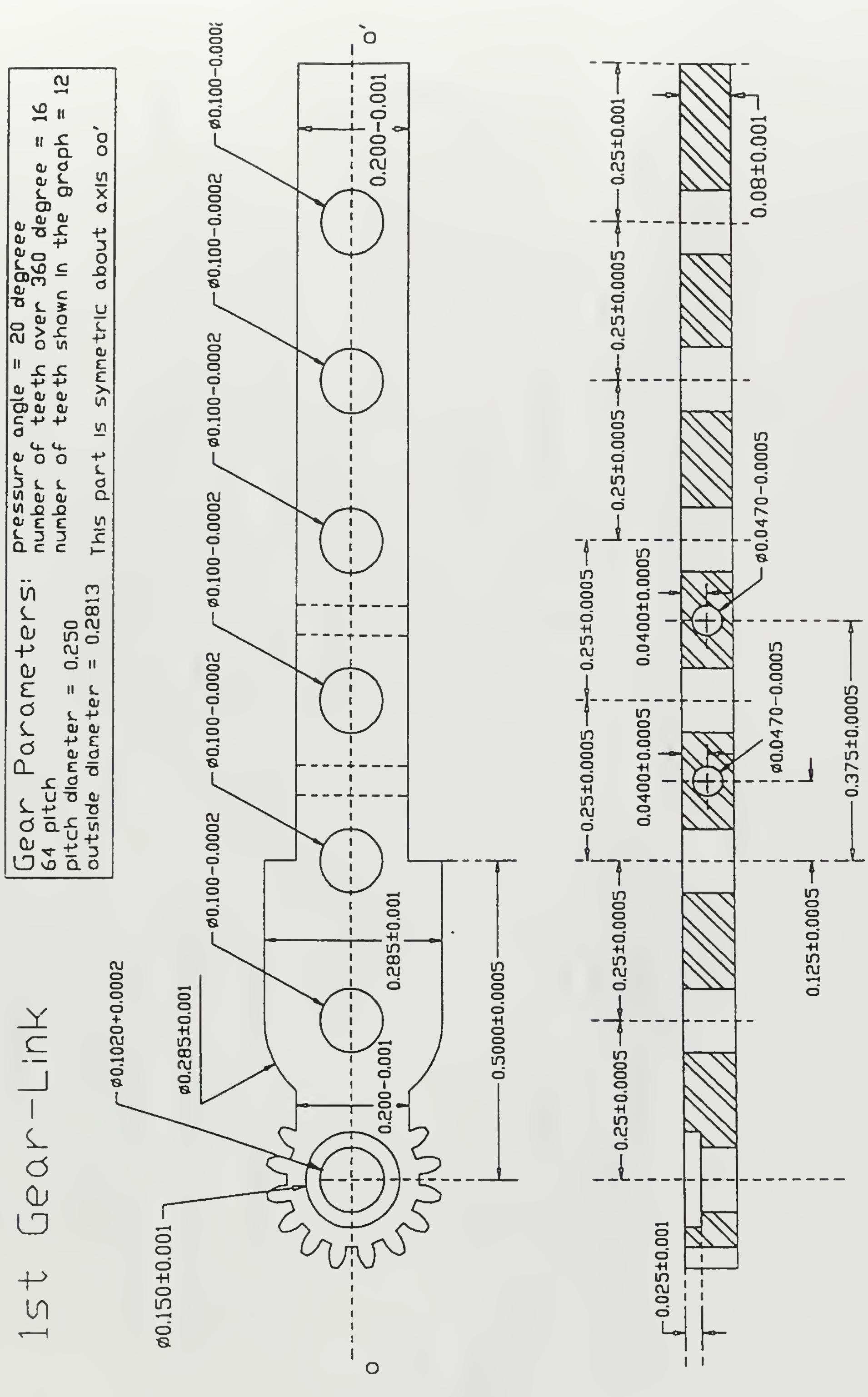

Figure 11. Drawing of 1st Gear Link

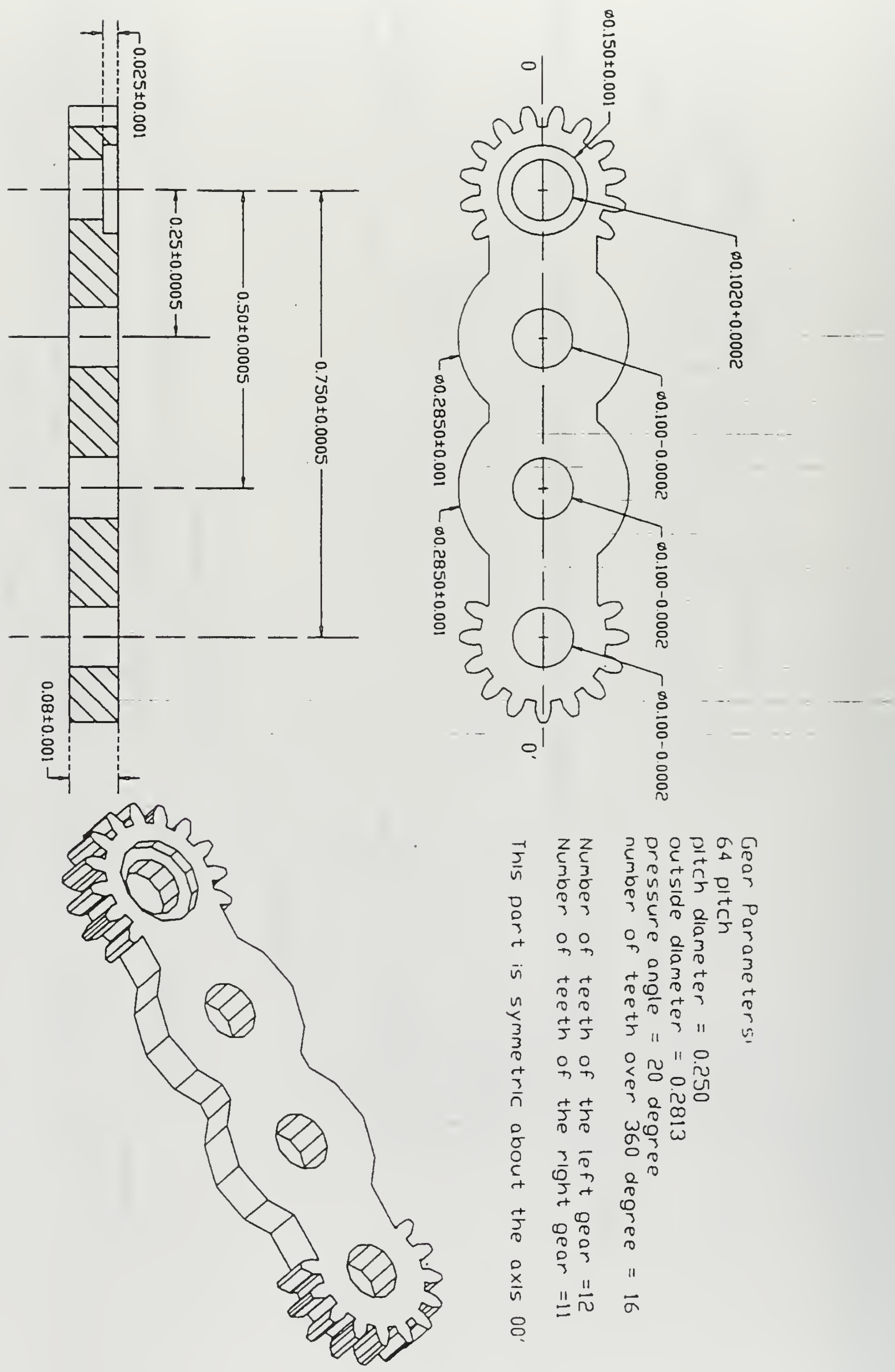

Figure 12. Drawing of Standard Connecting Gear Link

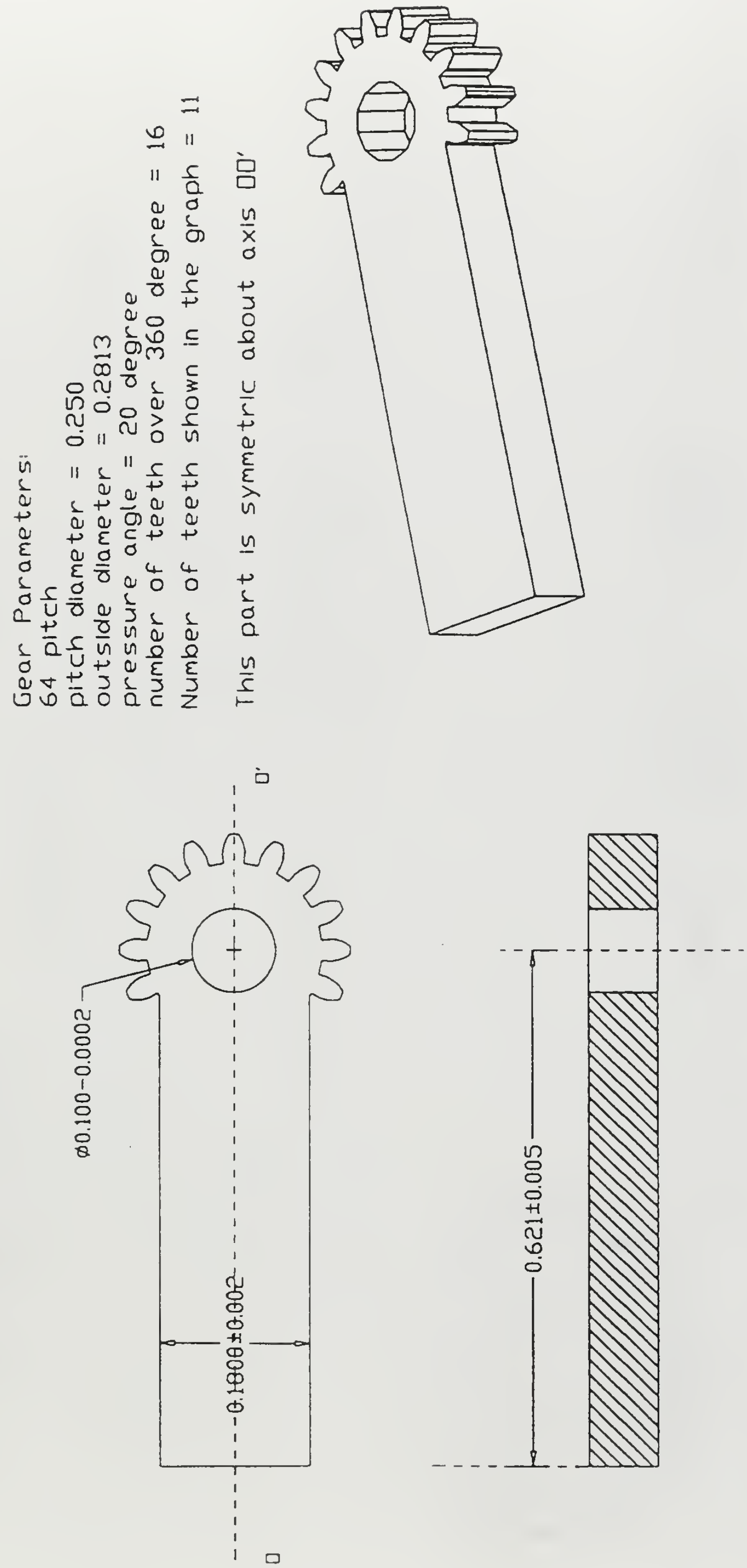

Figure 13. Drawing of End Gear Link

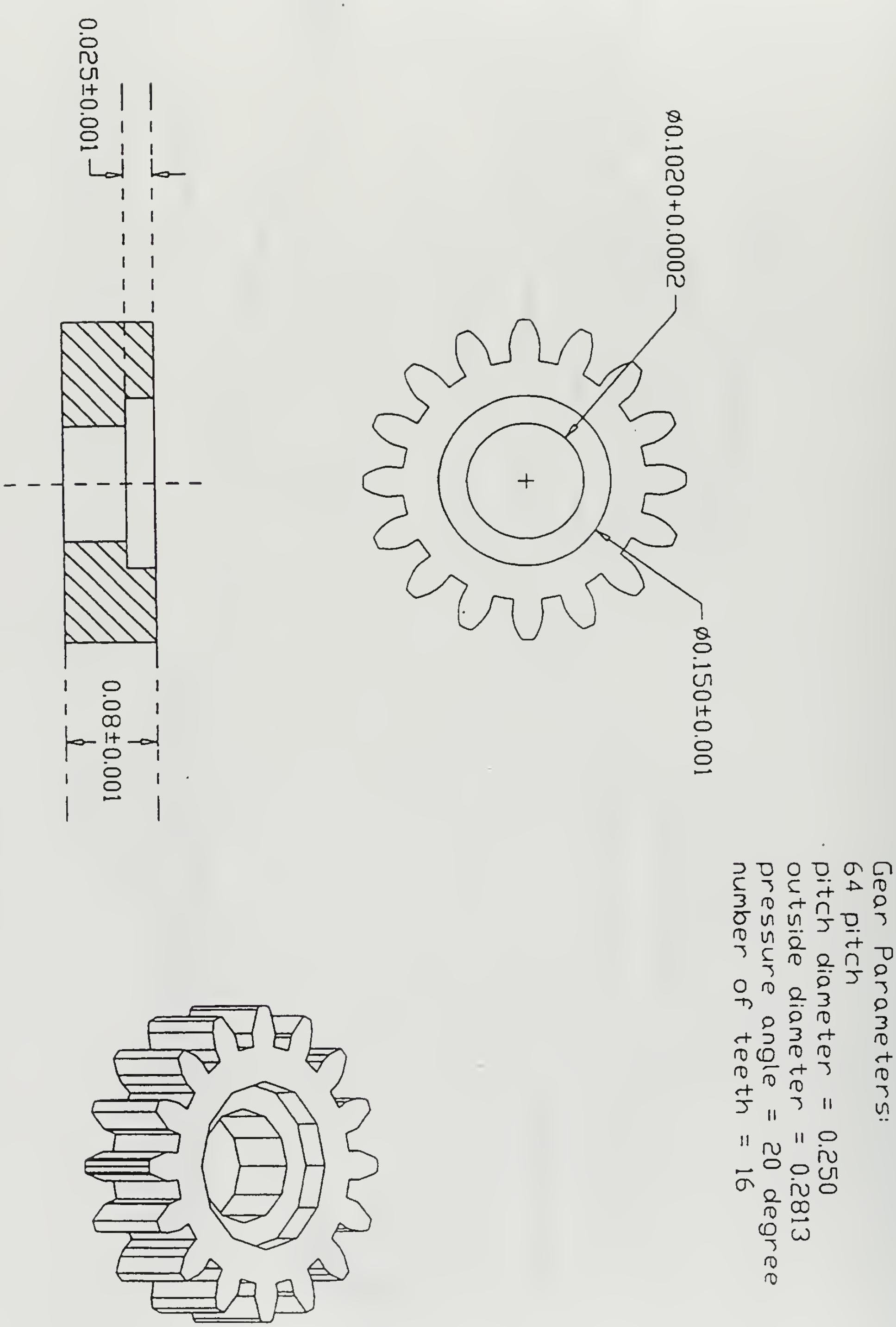

Figure 14. Drawing of 2 mm Standard Gear

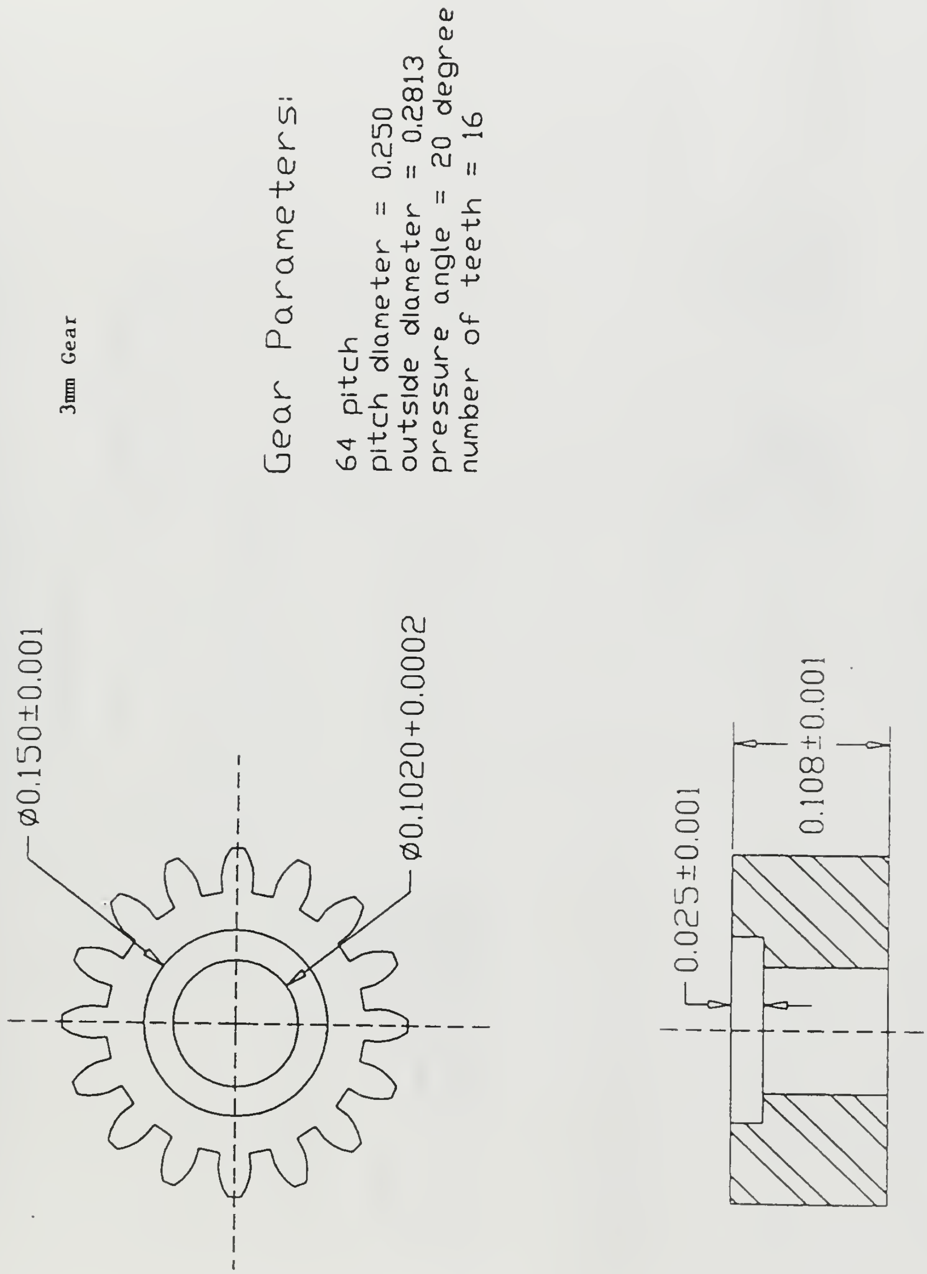

Figure 15. Drawing of 3 mm Gear

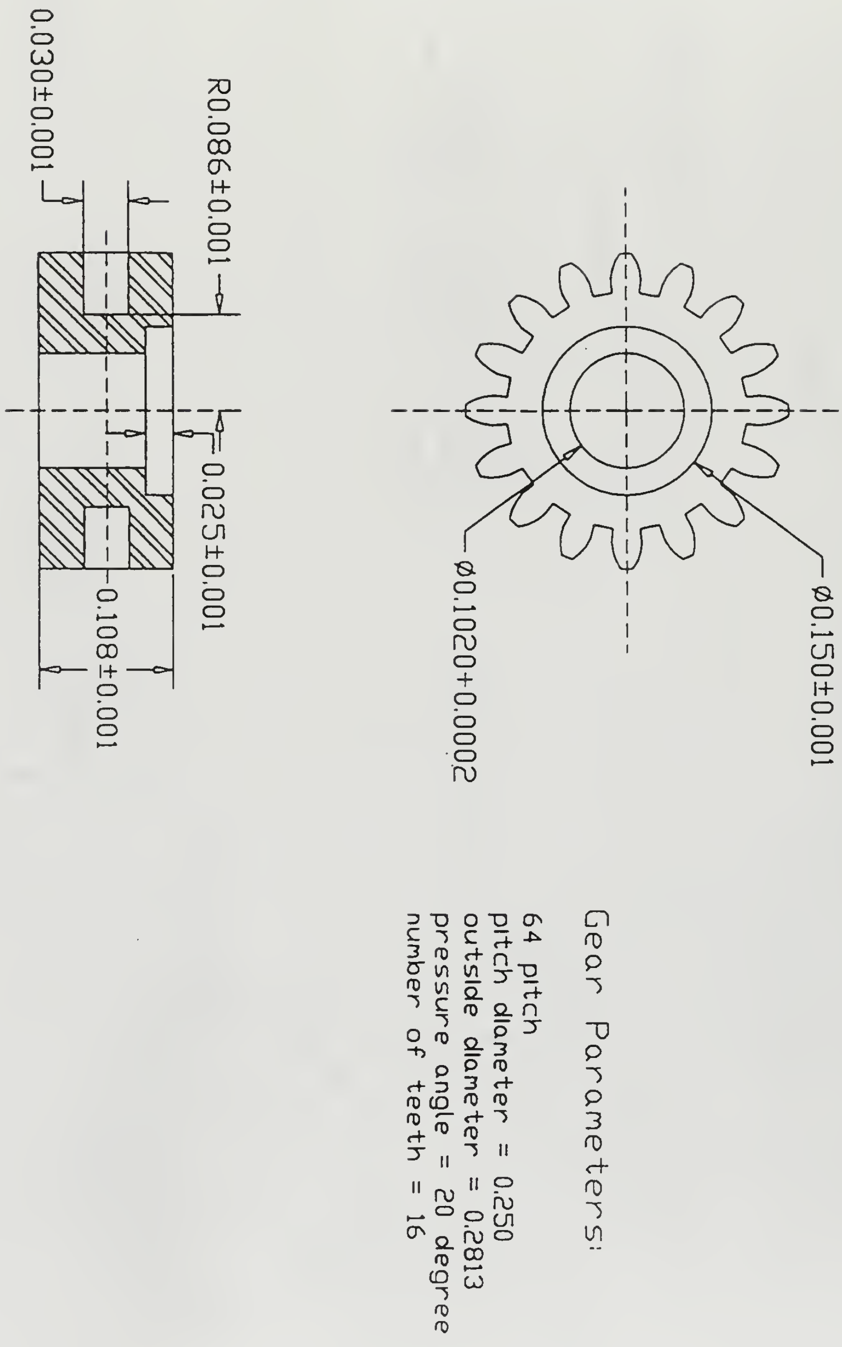

Figure 16. Drawing of 3 mm Gear with Slot

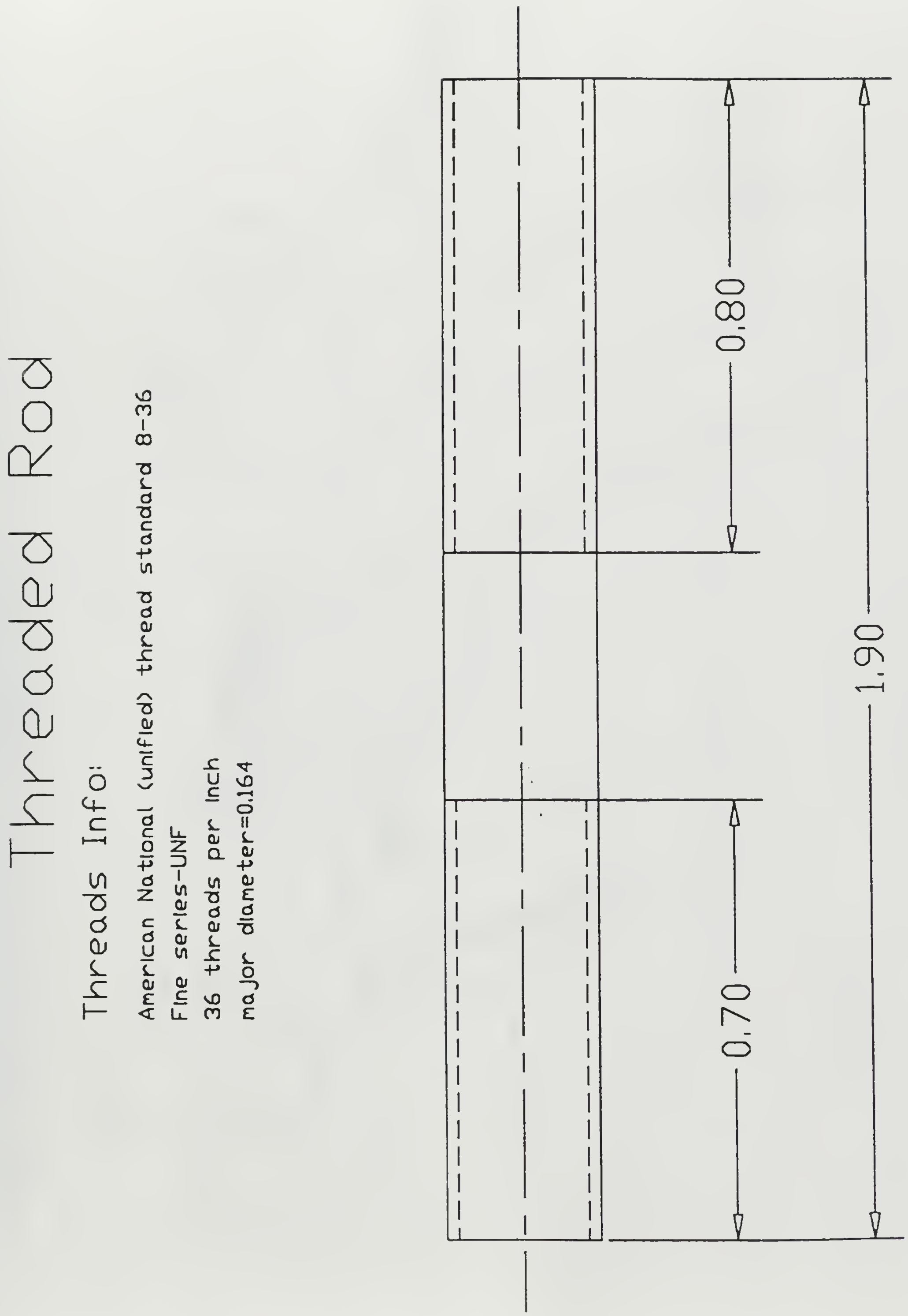

Figure 17. Drawing of Threaded rod

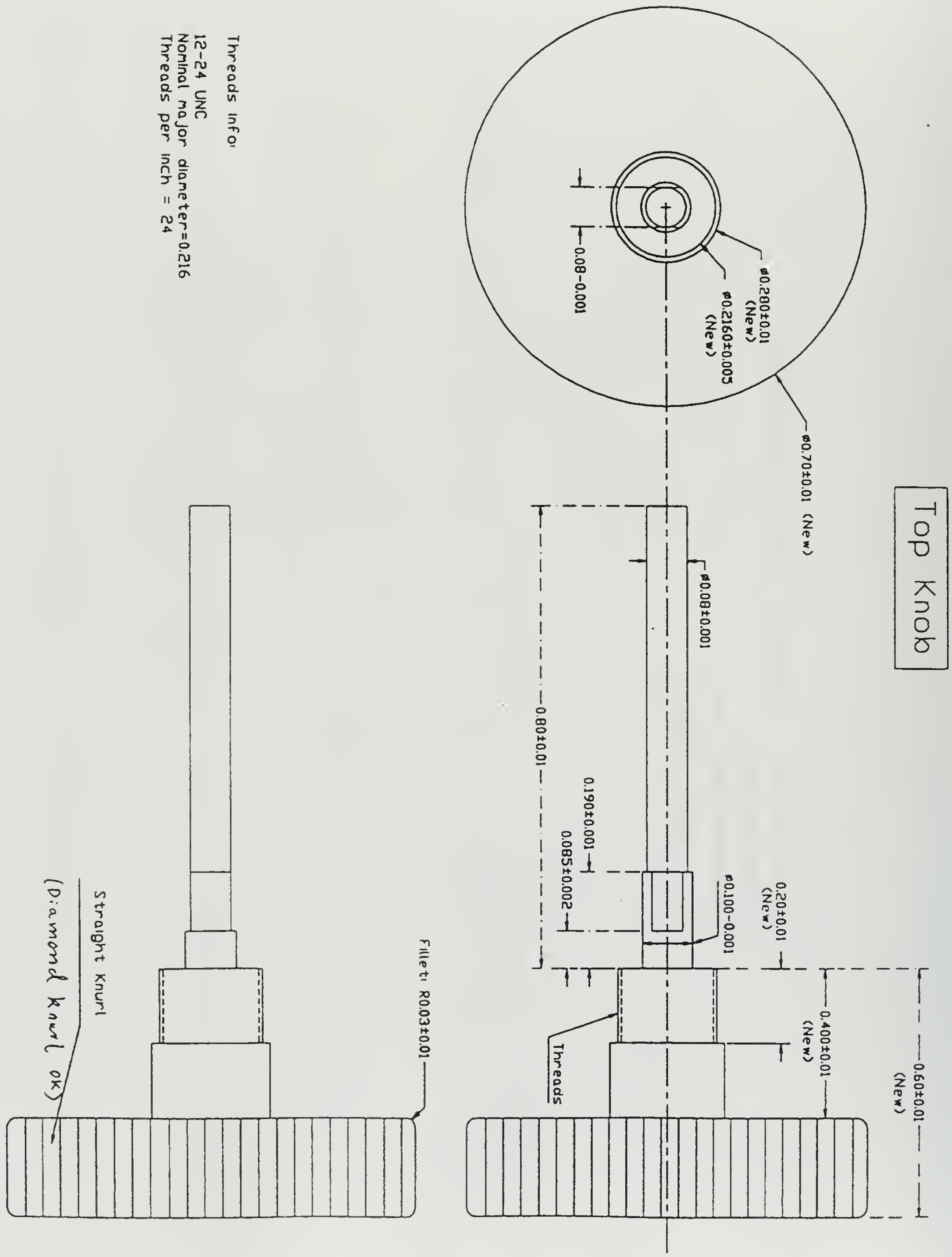

Figure 18. Drawing of Top Knob

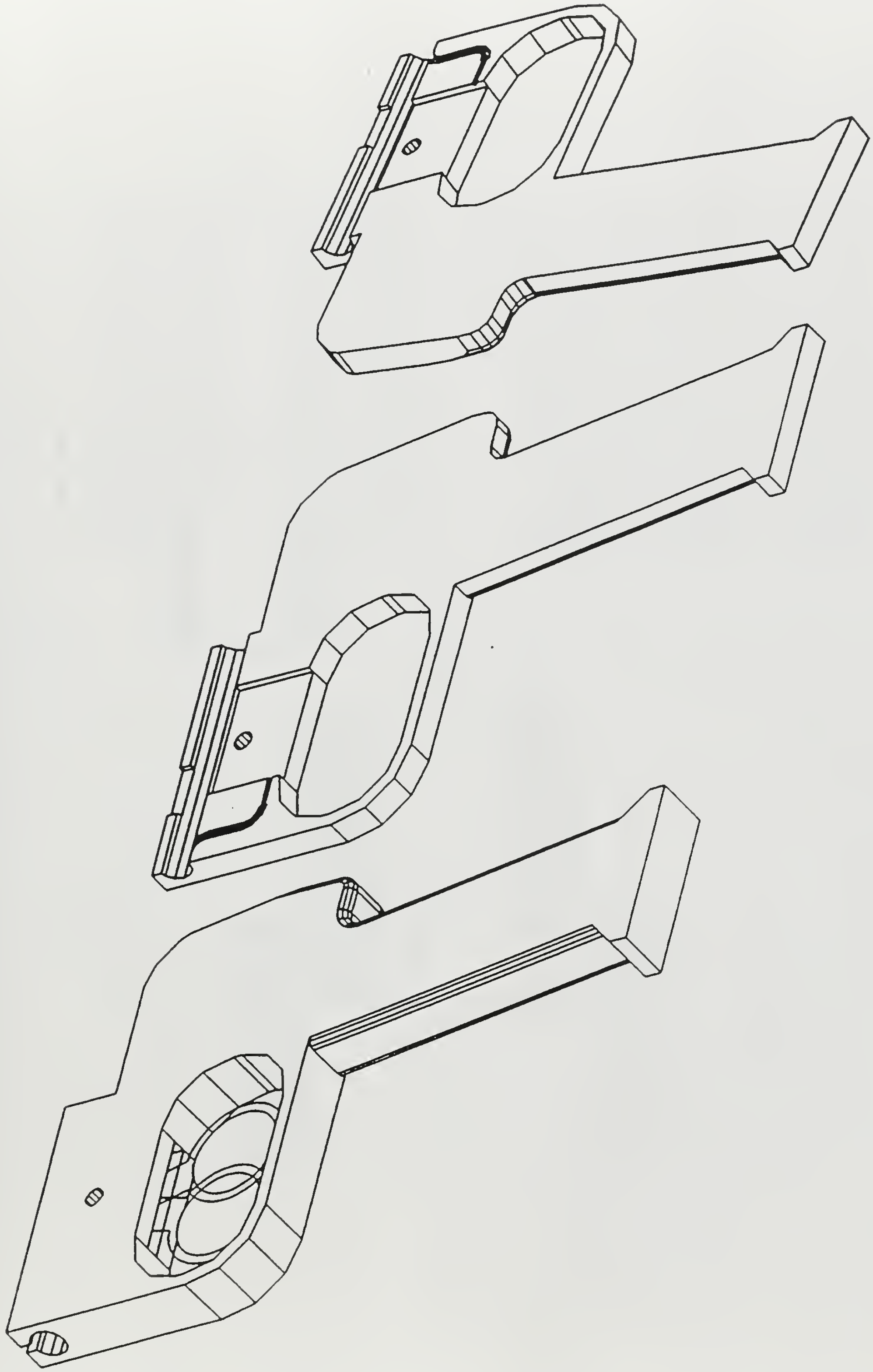

Figure 19. Drawing of Handle and trigger

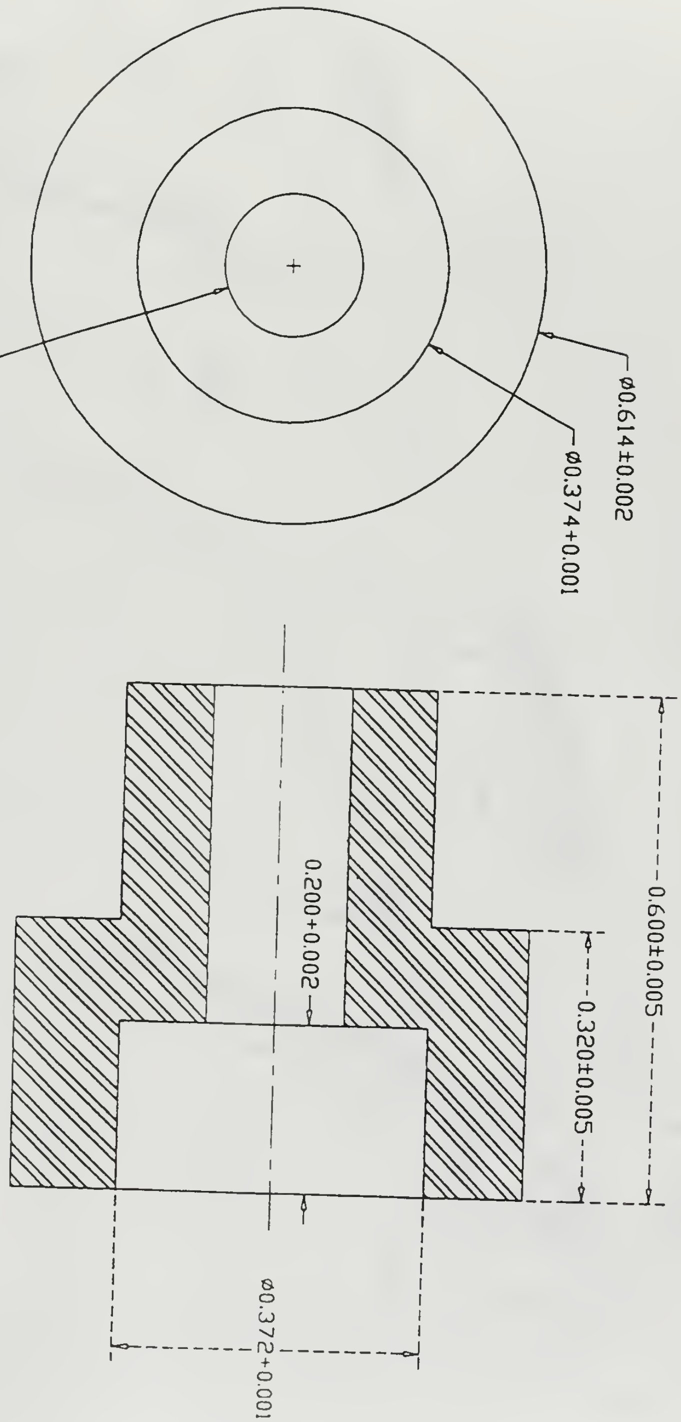

Figure 20. Drawing of End Plug

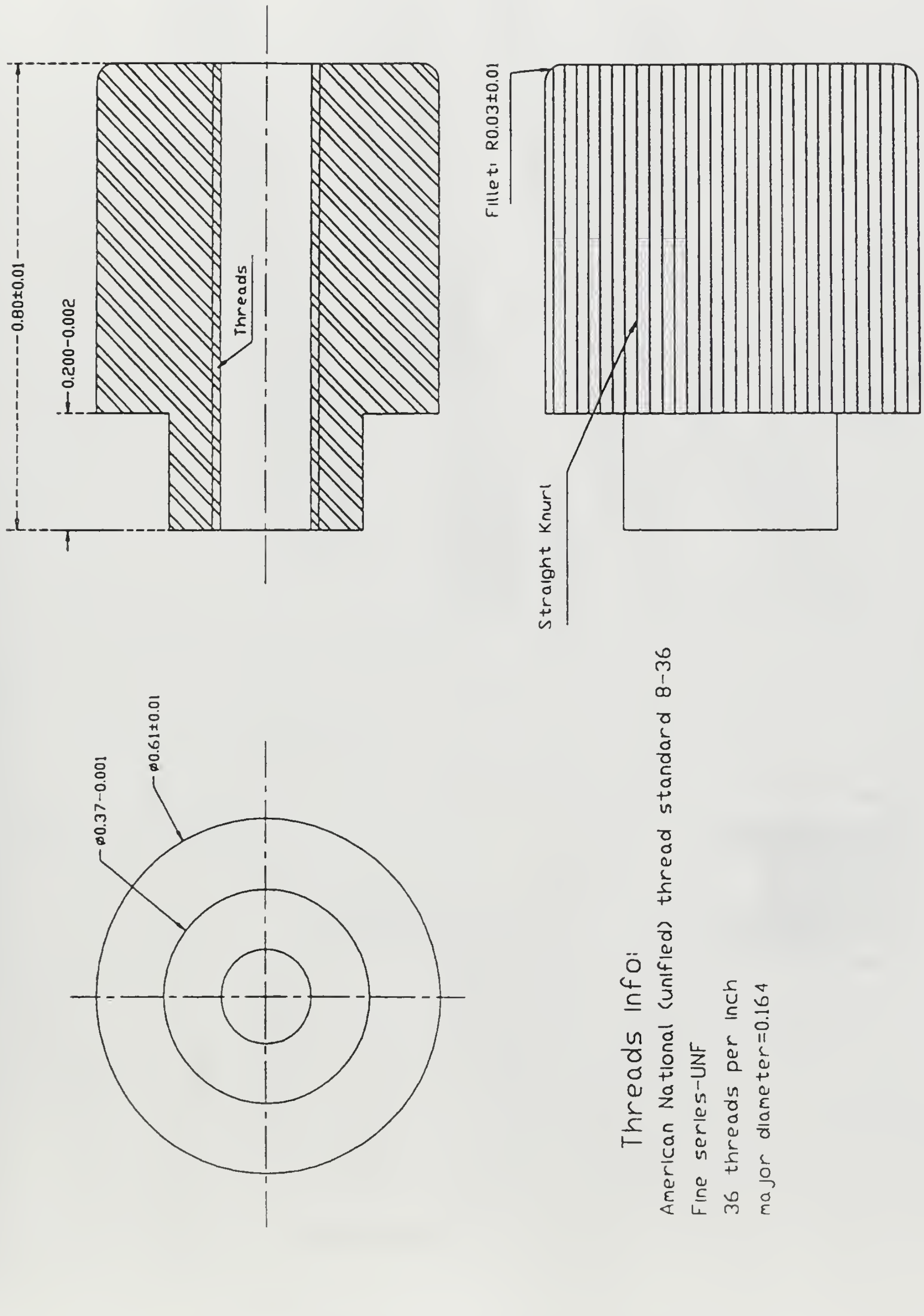

Figure 21. Drawing of End Knob

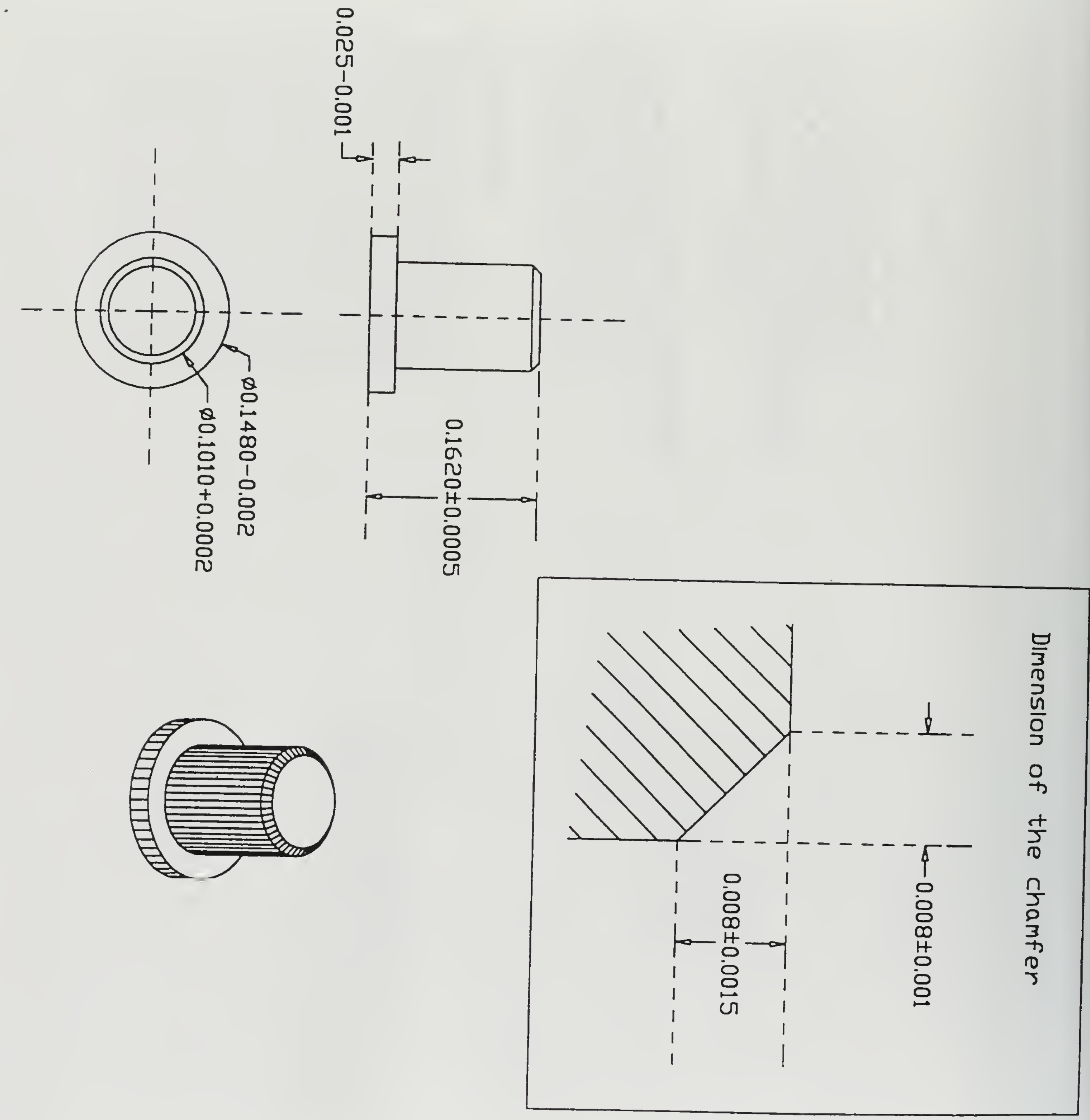

Figure 22. Drawing of Pin with Chamfer

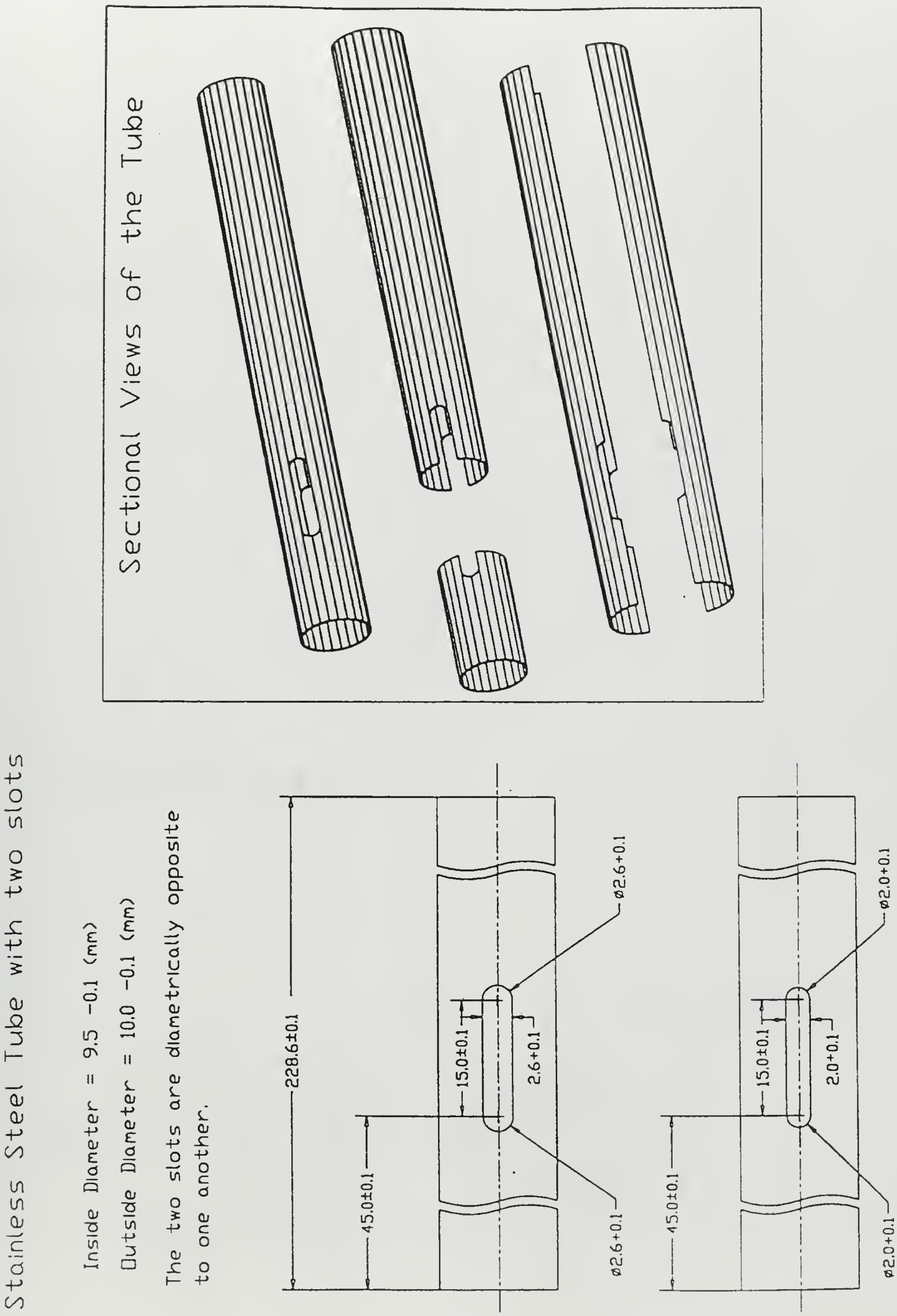

Figure 23. Drawing of Stainless Steel Tube with Slots

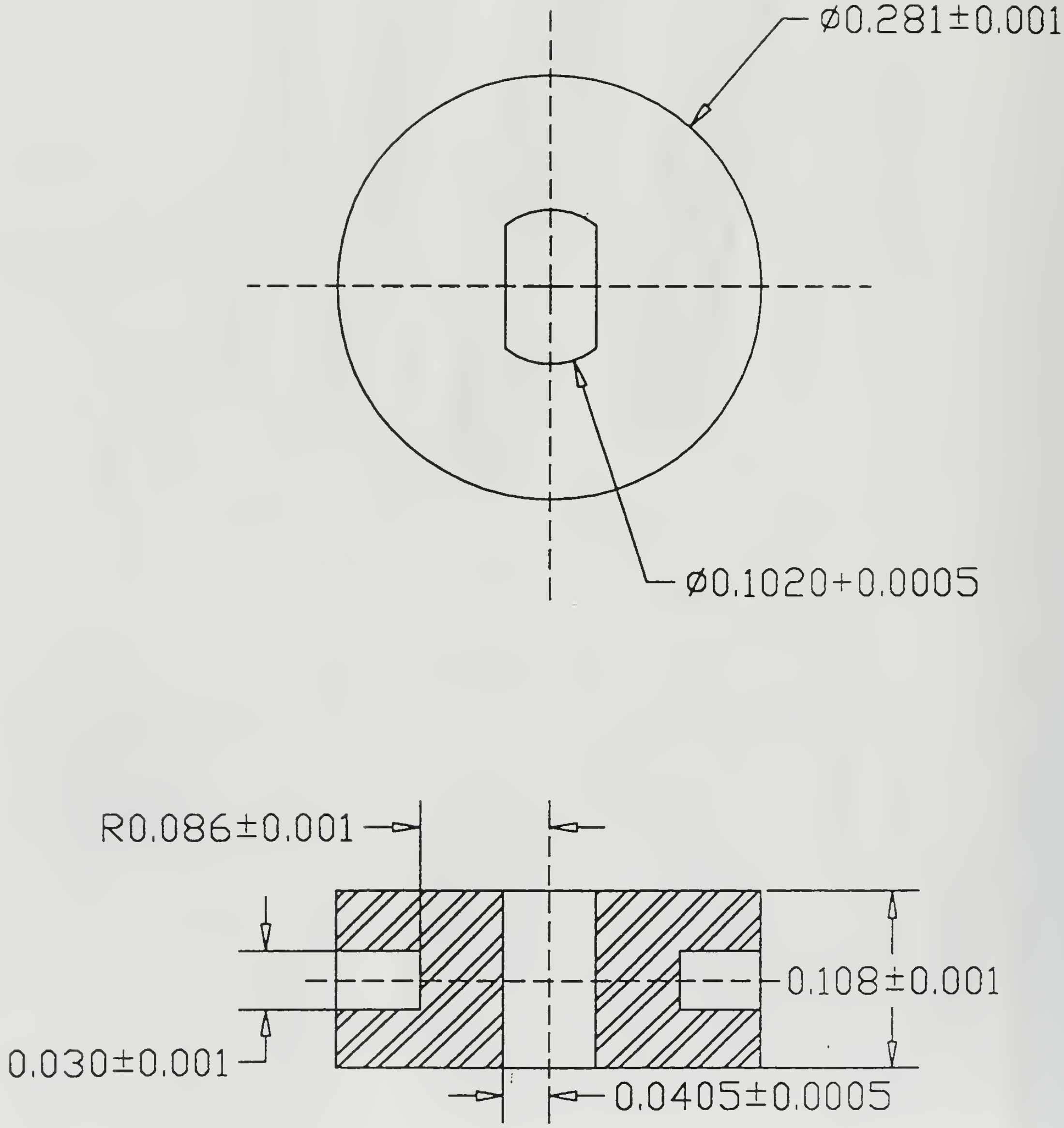

Figure 24. Drawing of 3 mm wheel

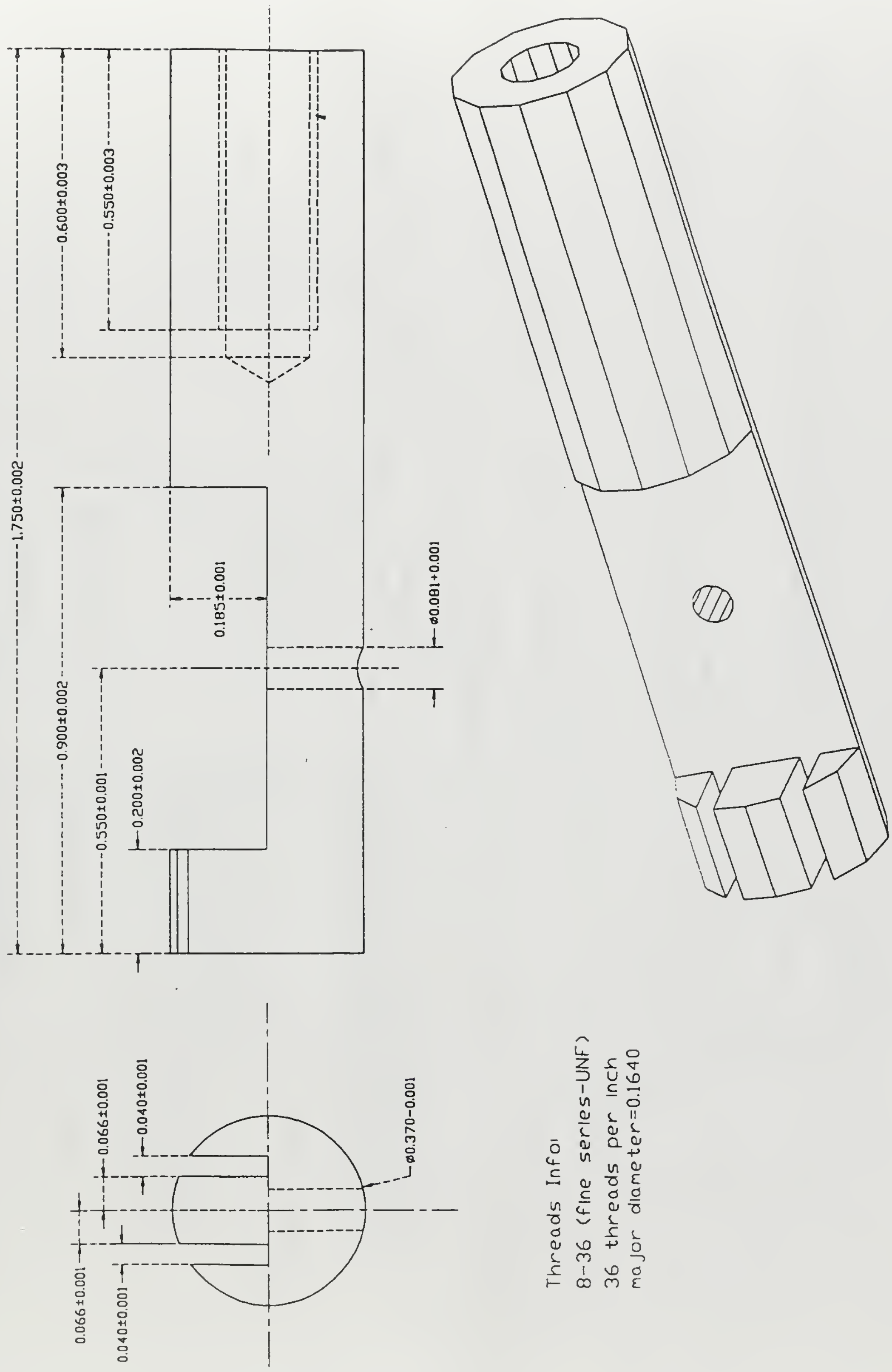

Figure 25. Drawing of Sliding Plug

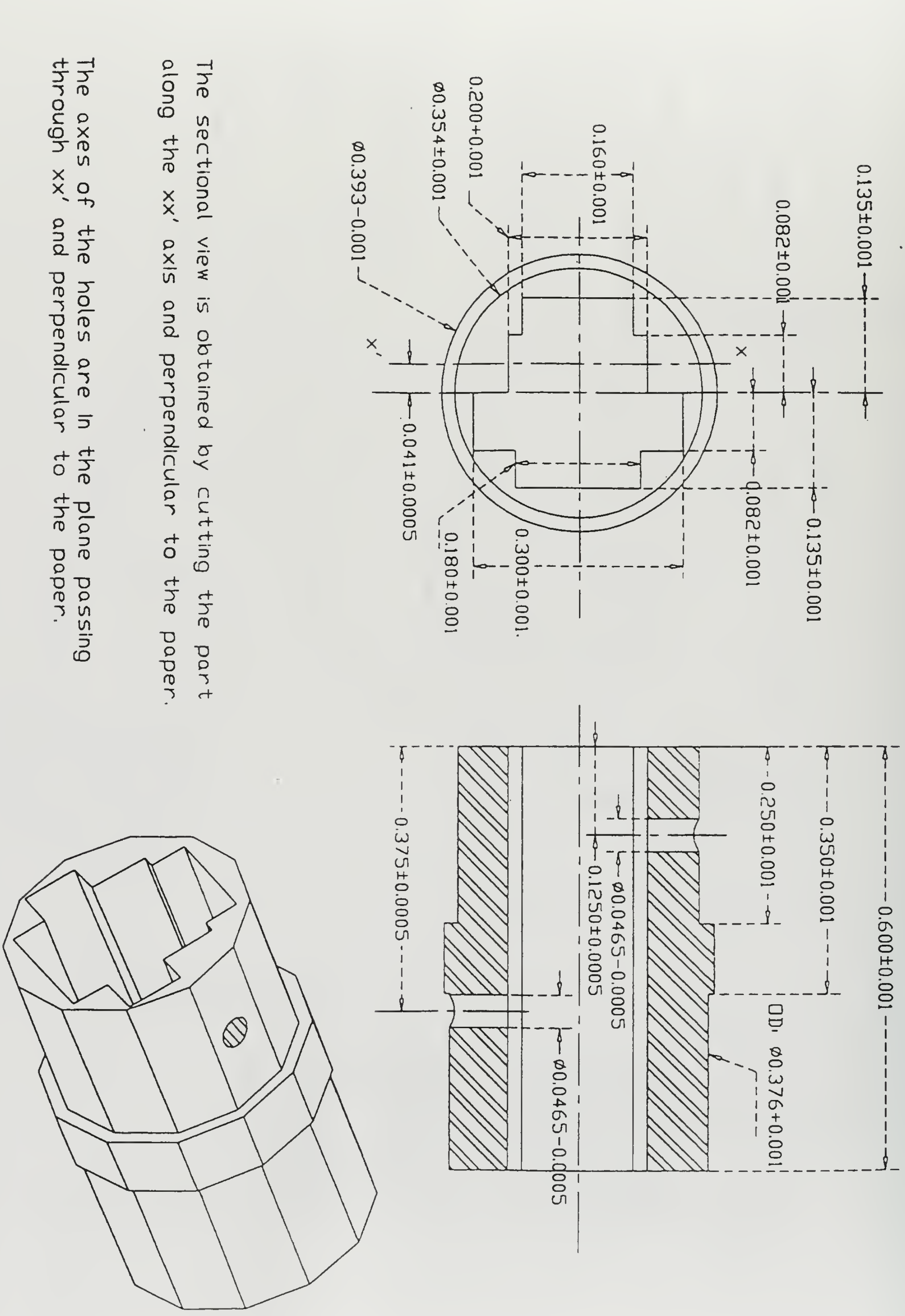

Figure 26. Drawing of Front Plug

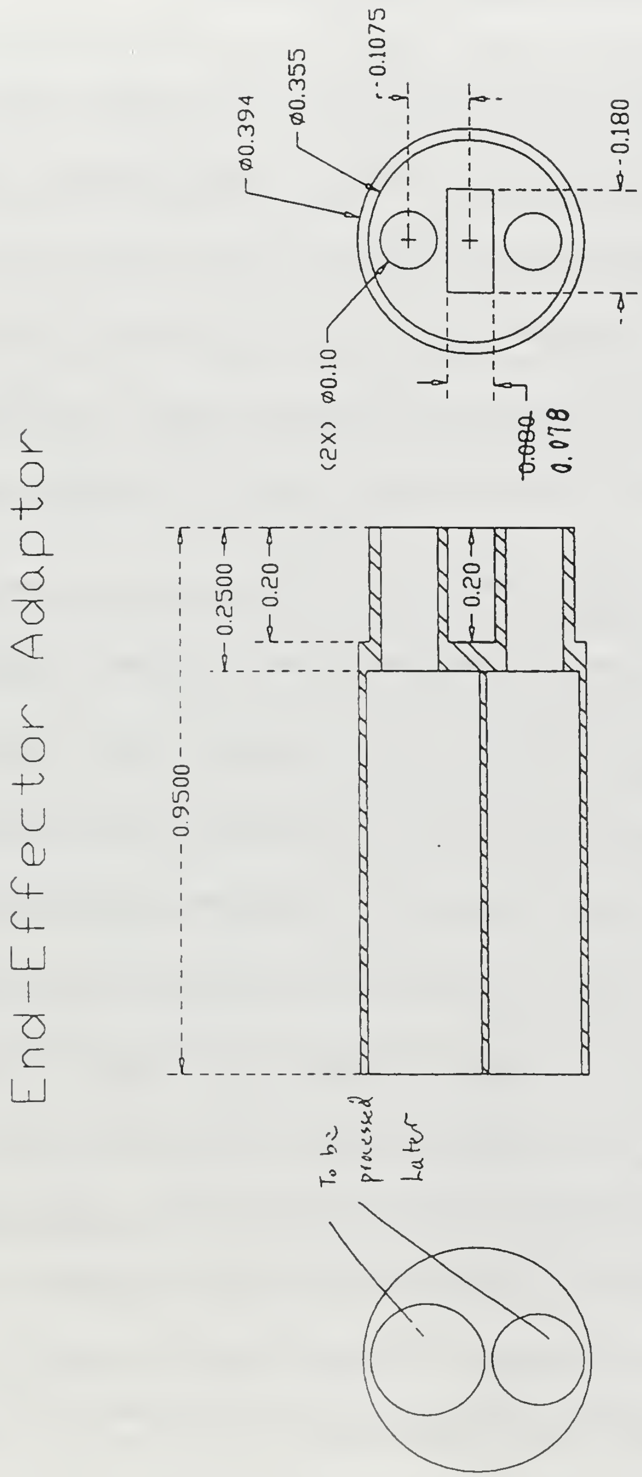

Figure 27. Drawing of End Effector Adapter

C. ASSEMBLY OF COMPONENT PARTS TO MAKE A DEXTEROUS SURGICAL INSTRUMENT

Each of the component parts designed in the previous section must be assembled together so that they can function as one dexterous surgical instrument. Figure 10 is a drawing of how the dexterous surgical instrument will look when all of the component parts are assembled. To understand how each of the component parts function the dexterous instrument will be broken into the following systems: 1.) AMMIS system 2.) Rigid surgical tool system 3.) Pulley Articulation System 4.) Endeffector system.

The AMMIS sub system is built from the following parts: 1st gear link, standard connecting gear link, end gear link, 2 mm standard gear, 3 mm gear, 3 mm gear with slot, and pin with chamfer. The building block of the mechanism is Link 0 or the base link see Figure 2. The component part named 1st gear link is the base link for the mechanism see Figure 11. The link has six gears mounted to it. Each gear is mounted by press-fitting the pin with chamfer to secure to the gear to the link. Starting at the end marked O prime in Figure 11, the first gear to be mounted will be the 3 mm thick gear with slot. The slot is made so that a cable can be wrapped around it. This will be used in the pulley articulation system. The next gear working to the left of Gear 1 will be another 3 mm thick gear. This gear has no slot. The purpose of this gear is to ensure that the 3 mm gear with a slot has an effective thickness of 2 mm where gear one and gear two mesh. This keeps the contact area larger, there-by reducing the amount of local stress concentrations. The next four gears are the 2 mm thick standard gears. The last hole on the base link is

where Link 1 is attached. For Link 1 through Link 3 in Figure 2 the standard connecting link part will be used. The end that is not countersunk on Link 1 is attached to the countersunk end of Link 0 see figure 12. Link 1 is also oriented so that the countersunk portion on Link 1 is on the opposite side as the countersunk portion on Link 0. Next, two 2 mm standard gears are attached to Link 1. The last hole on Link 1 is where Link 2 is attached. As before, the end that is not countersunk on Link 2 is attached to the countersunk end of Link 1. Link 2 is also oriented so that the countersunk portion on Link 2 is on the opposite side as the countersunk portion on Link 1. The process is repeated as before until Link 4 or the end link.

To attach the AMMIS to a surgical tool the tool must be specially built in order to attach the AMMIS. The rigid surgical tool system is built for this purpose. The rigid surgical tool system has the following component parts: Handle, trigger, end plug, stainless steel tube with slots, and front plug. The stainless steel tube with the slots is the building block for this system. The slots are oriented inside the handle so that they line up with the slot on the top of the handle. The end plug is attached to the end of the tube where the handle is. The front plug is placed on the front end of the tube. The front plug is oriented so that the end with the smaller outside diameter faces outward. It is also rotated so that the widest rectangular section is on the top side of the tube in a horizontal position.

The AMMIS is attached to the rigid surgical tool by attaching Link 0 to the front plug. The link is run through the rectangular section that is level with the set screw holes

and is fastened to the surgical tool with set screws. Now that the AMMIS is attached to the surgical tool we will discuss the articulation of the surgical instrument.

The pulley articulation system has the following parts: sliding plug, 3 mm wheel, top knob, threaded rod, end plug, and end knob. The sliding plug is placed in the tube with the flat side horizontal and facing the top of the tube. The end of the plug with two slots for the cable will be facing forward toward the AMMIS. The plug is positioned inside the tube so that the flat platform area is below the slots in the stainless steel tube. On the flat platform area of the sliding plug the 3 mm wheel is attached by passing the shaft of the top knob through the top of the handle and stainless steel tube, and through the 3 mm wheel. A cable is then run around the 3 mm wheel through the two slots at the front of the sliding plug and around the 3 mm gear with a slot ,on Link 0 of the AMMIS. The end plug is attached to the end of the tube and the end knob is positioned inside the opening of the end plug. The threaded rod is connected to the end knob and the sliding plug. To articulate the AMMIS we can turn the top knob which turns the cable system and drives the driver gear on Link 0. The tension of the cable system can be adjusted by turning the end knob which in turn moves the sliding plug and changes the tension in the cable. The pulley articulation system provides a smooth transmission of power from the turning knob to the driver gear to articulate the AMMIS. To complete the design of a dexterous surgical tool the AMMIS must be fitted with an endeffector.

The endeffector is attached by putting the endeffector adapter on the end link of the AMMIS. Then the endeffector, such as a pair of scissors, can be placed on the

adapter. The endeffector can be actuated by running a push pull cable from the endeffector through the inside of the tube to the handle. The cable is then run through the small tunnel in the handle toward the trigger. It is attached to the trigger so that by moving the trigger it will actuate the endeffector. This will give a complete design for a dexterous surgical instrument.

V. SUMMARY

A. ADVANTAGES

The AMMIS has the following advantages and salient features:

a) The AMMIS is capable of fine and dexterous manipulation. It can be designed to adopt a serpentine curve of tight radius and make bends of 180 degrees or more bi-directionally by using even and odd number of gears in successive links or by using multiple actuators.

b) The AMMIS can be a multi-purpose surgical tool since it is capable of carrying both a miniature camera (a 5 mm or 0.20 inch diameter camera is commercially available) and an end-effector such as a pair of scissors or gripper.

c) The AMMIS has sufficient structural rigidity to apply forces on body tissue that would be required during standard surgical procedures, such as cutting, suturing, etc.

d) The compact kinematic structure of the AMMIS simplifies the task of control of its articulated motion.

B. POTENTIAL APPLICATIONS

The AMMIS has potential applications in each of the following configurations:

a) Manual controlled AMMIS: This apparatus would consist of a stainless steel tube with an AMMIS connected at one end and a handle mounted at the other. The handle would be used for the manual control of articulation of the AMMIS and the control of the surgical tool that would be mounted at the distal end of the AMMIS. This device will provide enhanced dexterity.

b) Computer controlled AMMIS: In this configuration the AMMIS would serve as the micro-manipulator of a macro-micro manipulator system to be used for complex MIS procedures. The AMMIS would be supported at the end of the macro manipulator and together they will perform surgical operations under supervisory control provided by a surgeon on-site.

c) Tele-operated AMMIS: The compact design, the simplicity of control and the quick response of the AMMIS makes it an ideal candidate for tele-surgery. Along with suitable image processing techniques, a computer controlled AMMIS can be extended to tele-surgery.

C. CLINICAL PERSPECTIVE

The number of MIS procedures is beginning to plateau because of limitations of instrumentation. There are numerous procedures which could be performed if the instruments were articulated to provide additional dexterity which would closely mimic

our natural dexterity. Examples include gastric, liver or other solid organ resections, hiatal hernia repair, colon surgery, etc. The common difficulty encountered is due to the inability to insert instruments around and behind organs, such as encircling the esophagus in nissen fundoplication or isolating the arteries, veins and bile ducts during hepatitic surgery.

Suturing is a common task for most surgical procedures, and dexterous instrumentation alone will greatly enhance and increase the number of surgical procedures. Currently, suturing poses as a challenging task to most surgeons because of the precision required in needle tip placement. With limited dexterity in current instrumentation, it is not possible (or possible only with great difficulty) to insert sutures at oblique angles to the suture holder shaft. With an articulated instrument any angle can be achieved for the precision required. some of the MIS procedures involving suturing are currently being done by only a few individuals: the availability of dexterous instrumentation will allow more surgeons to bring these complex procedures to a greater number of patients.

D. CONCLUSION

This research has produced a simple and compact design methodology of an articulated manipulator expected to be used extensively for MIS in the near future. The design has meet and exceeded the design criteria. There are a number of non-medical areas, such as aviation maintenance and engine inspection that could provide a spin-off where this articulated mechanism could be used.

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